# Bone Conduction Effecting the Peripheral Hearing Organ

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## Introduction

Bone Conduction (BC) is the transmission of acoustical or mechanical vibrations to the hearing organ via the body, particularly the head. In order to investigate the underlying mechanisms the Bochum Head and Ear Model (BOHEAR) has been developed. This finite element model comprises the skull, the peripheral hearing organ, as well as the brain, and the soft tissue. In the study presented here, predictions of the BC components were made by means of BOHEAR. The predictions were compared with calculations of air conduction (AC) movements from the same model. Furthermore the pattern of vibration of the tissue enclosing the hearing organ was analyzed, in order to gain an understanding of the underlying mechanisms.

## The Model

BOHEAR is a revised version of a previous model [1]. The model confirms well to in vivo measurements of real heads of different kind. The skull and the soft tissue are represented by solid elements. The bulk of the brain is also modelled with solid elements. Only the boundary layer interfacing the brain and the skull consists of fluid elements. This boundary layer represents the cerebrospinal fluid (CSF). More details regarding the geometry and mechanical parameters of all model components are presented in [2,3].

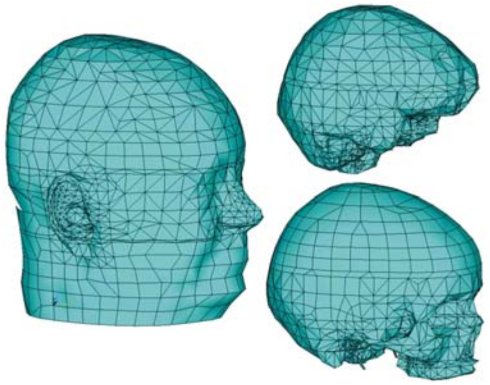

**Figure 1:** The Bochum Head and Ear Model (BOHEAR). The finite element model comprises the skull, the brain, the soft tissue, and in particular the peripheral hearing organ.

## Separation of the Components

The definition of BC components is arbitrary to a certain extend. We defined three reasonable major components [2]: First, the inertial component of the ossicles, which describes the inertial vibrations of the ossicular chain (without the tympanic membrane). Second, the acoustomechanical component of the outer and the middle ear, that comprises the vibrations of the air in the ear canal and the middle ear cavities as well as the vibrations of the tympanic membrane due to movements of the canal and the cavity walls. Third, the inner ear component due to the inertial movement of the fluid and the deformation of its bony shell.

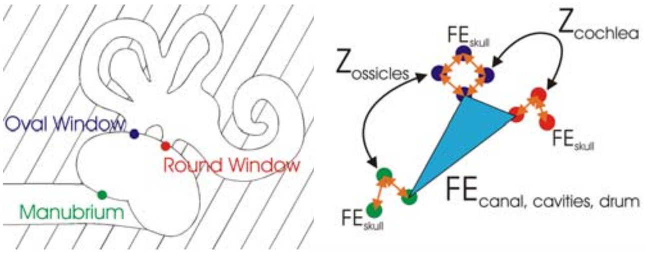

**Figure 2:** In order to separate the bone conduction components the model has been split up at the manubrium coupling region, the oval and the round window (left). The natural boundary conditions have been restored by elements which represent the neighbouring model parts in terms of system impedance matrices Z of multi ports (right).

The definition of the components was determined by the locations which are suitable for splitting up the model. Such places are rigid regions (mechanical) or areas with only small spatial pressure variations (acoustical). Hence we chose the area at which the manubrium mallei is coupled to the ear drum, the stapes footplate at the oval window and the entrance area of the round window niche. In order to restore the natural boundary conditions at the interface locations, special element types have been developed which represent the adjacent parts of the model in terms of multi port system impedance matrices Z. As the matrix components were determined for AC, the relative movement of the interface areas with respect to the bone was taken as input for the Z-elements. While performing a harmonic analysis the relative movements were calculated via constraint equations for the corresponding degrees of freedom (example for acoustomechanical component in fig. 2).

## The Inertial Component of the Ossicles

As could be expected from literature the relative movement of the ossicles and the bone increases with frequency for pure translational excitation. At higher frequencies the relative movement should equal the movement of the surrounding tissue, because the ossicles come to a rest due to their inertia. However, the model predicts a fairly high relative motion at low frequencies. This at least unexpected behaviour might be caused by the definition of the component (no direct BC excitation at the drum coupling area) and the rotational components of the natural excitation.

## The Acoustomechanical Component

The acoustomechanical component of the outer and the middle ear is presented here by means of the displacement perpendicular to the stapes footplate. The model has been excited by a force of 1N at the temporal bone, directly behind the pinna. As can be seen from fig. 3 the relative movement (cyan) is about 20dB smaller than the absolute movement (magenta). One reason for this most probably is, that the masses of the air and of the ear drum are so small that inertia is almost negligible up to 10kHz.

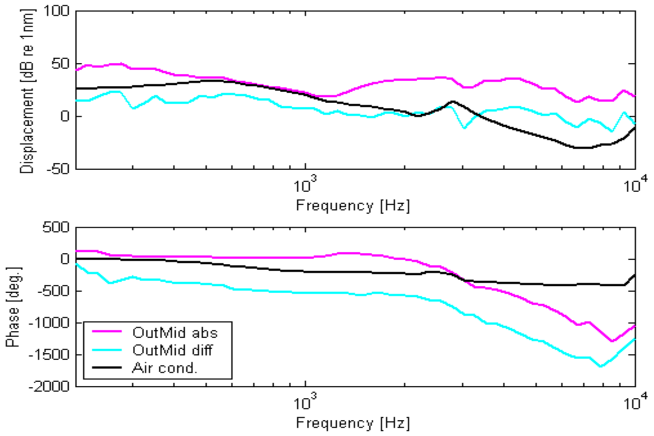

**Figure 3:** The acoustomechanical component and air conduction (1Pa at the entrance of the ear canal) in terms of the vibrations perpendicular to the stapes footplate.

A main effect of this component is the fairly strong vibration of the cartilaginous part of the ear canal. This effect becomes even more important when the ear canal is occluded. Fig. 4 shows that in this case the amplitude of the stapes footplate movement increases significantly at low frequencies. Hence the model predicts the occlusion effect in a correct manner.

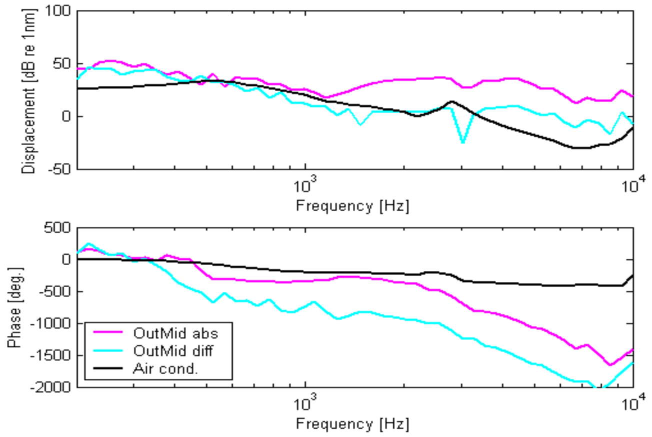

**Figure 4:** The acoustomechanical component in terms of the vibrations perpendicular to the stapes footplate. When the ear canal is occluded the amplitude of the relative displacement increases significantly at low frequencies.

## The Inner Ear Component

In fig. 5 the bulk of the velocity of the basilar membrane (BM) is depicted as a function of the distance from the cochlear base and the frequency. Red represents high velocity amplitudes, blue low amplitudes. The frequency space mapping is shown by the blue line which connects the places of maximum amplitude. A comparison with the corresponding map for air conduction shows that the frequency place mapping is exactly the same for air and bone conduction. Furthermore the phase of the BM velocity continuously decreases from base to apex, which reveals that the phenomenon of travelling waves occurs for all frequencies.

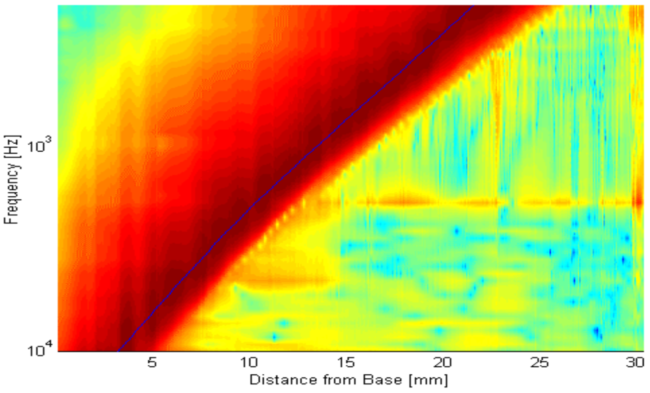

**Figure 5:** Frequency place mapping for bone conduction: The basilar membrane velocity as a function of the distance from the cochlear base and the frequency. The blue line connects the places of maximum amplitude per frequency.

Another important question is, as to whether the bony shell of the cochlea is significantly deformed or not. Thus the movements of the points on the boundary line of several cross-sections through the bony cochlea have been investigated. The degree of deformation was determined by the maximum difference of the displacements of two points. Deforming vibrations are about 30dB lower in amplitude than the pure translational movements in the whole frequency range (fig. 6). This is confirmed by the fact, that the mean translational displacement (red/blue) equals the maximum displacement (magenta/cyan). Consequently deformation of the cochlea plays only a minor role in BC up to 10kHz.

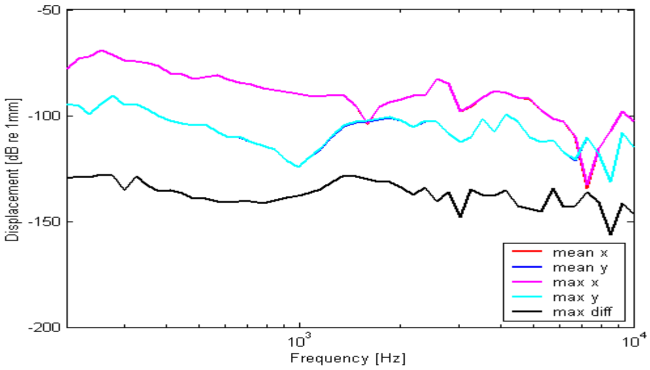

**Figure 6:** Translation (mean and maximum of all points per frequency) and deformation (maximum difference per frequency) of a cross-section through the bony cochlea.

## References

[1] H. Taschke, Y. Curdes: Knochenschall – Schwingungsformen des menschlichen Schädels. in: Fortschritte der Akustik - Daga, Bochum, 2002, 62-63

[2] H. Taschke, M. Hülskemper: Knochenschall – Finite-Elemente-Berechnungen zur Innenohrkomponente. in: Fortschritte der Akustik - Daga, Hamburg, 2001, 169-170

[3] Y. Curdes, H. Hudde, H. Taschke: Modelling the Dynamic Behaviour of the Human Middle Ear Using the Finite-Element Method. Joint Congress CFA/DAGA, Strasbourg, 2004